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RESULTS OF Shelterwood Cutting in Western Hemlock

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Contents

	Page
INTRODUCTION	1
THE STUDY AREA	1
METHODS	1
Plot Layout	1
Treatments	2
RESULTS	5
Regeneration by 1971, 2 years after the removal cut .	5
Regeneration by 1965--simulating a two-stage harvest	12
Treatment effects on overstory characteristics	13
Lesser vegetation development	13
DISCUSSION AND CONCLUSIONS	19
LITERATURE CITED	21
APPENDIX	23
Data collection and analysis	23
List of plant species	25

Results of Shelterwood Cutting in Western Hemlock

Reference Abstract

Williamson, Richard L., and Robert H. Ruth
1976. Results of shelterwood cutting in western hemlock. USDA For. Serv.
Res. Pap. PNW-201, 25 p., illus. Pacific Northwest Forest and
Range Experiment Station, Portland, Oregon.

Twelve shelterwood densities, ranging from 38 to 235 square feet of basal area per acre, were created in a 60-year-old stand. Eleven years after the first cut, regeneration was heavily overstocked under all densities. Brush was adequately controlled by overstory densities of at least 90 square feet of basal area. Overstory volume growth per acre during the regeneration period was approximately proportional to number of trees. Based on clearcutting experience on similar western hemlock sites, shelterwood harvesting probably was not essential for successful regeneration at this location. However, shelterwood cutting is a viable alternative to clearcutting for harvesting and regenerating western hemlock.

KEYWORDS: Shelterwood cutting method, western hemlock, silvicultural systems, natural regeneration.

RESEARCH SUMMARY

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A test of three-stage shelterwood harvesting in 60-year-old western hemlock established 12 overstory densities, ranging from 38 to 235 square feet per acre (8.7 to 54.0 m² per ha) after the first cut. All overstory densities resulted in overstocking, with numbers of seedlings averaging 650 per acre (1,600 per ha) after the first cut; ranging from 1,100 to 24,400 per acre (2,700 to 60,300 per ha) after the second cut; and from 8,500 to 26,700 per acre (21,000 to 66,000 per ha) after the final cut.

The extremes of treatment resulted in lower numbers of seedlings than resulted from intermediate treatments. Numbers were lowest under the densest overstory stands after the second cut, and lowest

under the most open stands after the third cut.

Seedling height at the end of the study period increased as overstory density decreased.

Overstory trees showed no response to release in cubic-foot-volume growth, making stand growth approximately proportional to number of trees in the overstory.

Brush competition was not a serious problem in this area, averaging only 32-percent canopy density during the study. It appears, however, that the greatest densities of lesser vegetation that did occur under open stands inhibited

height growth of hemlock seedlings somewhat.

Since most land managers will opt for a two-stage harvest, regeneration results are also described after the second cut so that some idea of two-stage harvest results may be gained.

The shelterwood harvest system offers the land manager some flexibility from the standpoint of both securing regeneration and minimizing environmental impacts. Further flexibility is provided because land managers can clearcut or shelterwood harvest and be reasonably sure of adequate regeneration.

Introduction

The shelterwood system of establishing regeneration under the protection of the mature forest seems a logical harvest method for western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Hemlock is very shade tolerant, its seed germinates on the forest floor, and seedlings establish readily in the understory of a forest stand (Berntsen 1958). Nevertheless, clearcutting is the usual method of harvesting in the western hemlock type. Vast stands of second-growth hemlock that came in after clearcutting was done about the turn of the century attest to the general success of clearcutting.

Occasionally, however, problems arise in securing regeneration. These usually involve red alder (*Alnus rubra* Bong.) and brush encroachment, or locally severe site conditions. These problems should be less important under residual overstories after shelterwood treatment. Also, repeated thinning of young stands promotes seedling establishment in the understory. This condition points directly to shelterwood cutting as a logical harvest method (Ruth 1974). Finally, the burgeoning importance of esthetic appeal promotes a partial cutting harvest method in areas commonly in the public view.

Shelterwood characteristics in young-growth western hemlock were studied on the Hemlock Experimental Forest^{1/} near Hoquiam in western Washington. The objective was to evaluate shelterwood cutting for regenerating western hemlock on coastal sites. Study establishment was reported earlier (Herman 1962), and subsequently, a synopsis of interim results was published (Williamson 1966). This final report summarizes results 2 years after overstory removal (11 years after the first cut).

The Study Area

In 1960, before cutting, the 70-acre (28-ha) study area supported a well-stocked almost pure western hemlock stand about 60 years old. A few older trees, residual from old-growth logging, were scattered throughout the area. Hundred-year site index is estimated at 157 feet (48 m); cubic and Scribner volumes in 1960 averaged 8,700 cubic feet and 43,000 board feet per acre, respectively (609 m³ per ha). Average number of 6-inch (15-cm) d. b. h. and larger trees per acre was 274 (677 per ha), and their quadratic mean d. b. h. was 12 inches (30 cm). Trees smaller than 6-inch d. b. h. were generally scattered throughout the area. They were considered to be advance regeneration, and most were destroyed during logging.

The soil is Hoquiam clay loam having large soil moisture storage capacity.^{2/} The soil is deep and is derived from marine sediments.

Methods

PLOT LAYOUT

The 70-acre (28-ha) study area was divided into 12 compartments of approximately 6 acres (2.4 ha) each. A different treatment was applied to each compartment. Detailed measurements were made on a central acre in each compartment, except for two treatments where topography required two 1/2-acre (0.2-ha) tracts each (S-4 and S-5 in fig. 1). Within each acre, 24 to 26 one-milacre plots were established on a systematic grid. Details of data collection and analysis are in the appendix.

^{1/} Maintained in cooperation with St. Regis Paper Company, Tacoma, Washington.

^{2/} Robert F. Tarrant. Geology and soil characteristics of the Hemlock Experimental Forest. Unpublished report on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 1954.

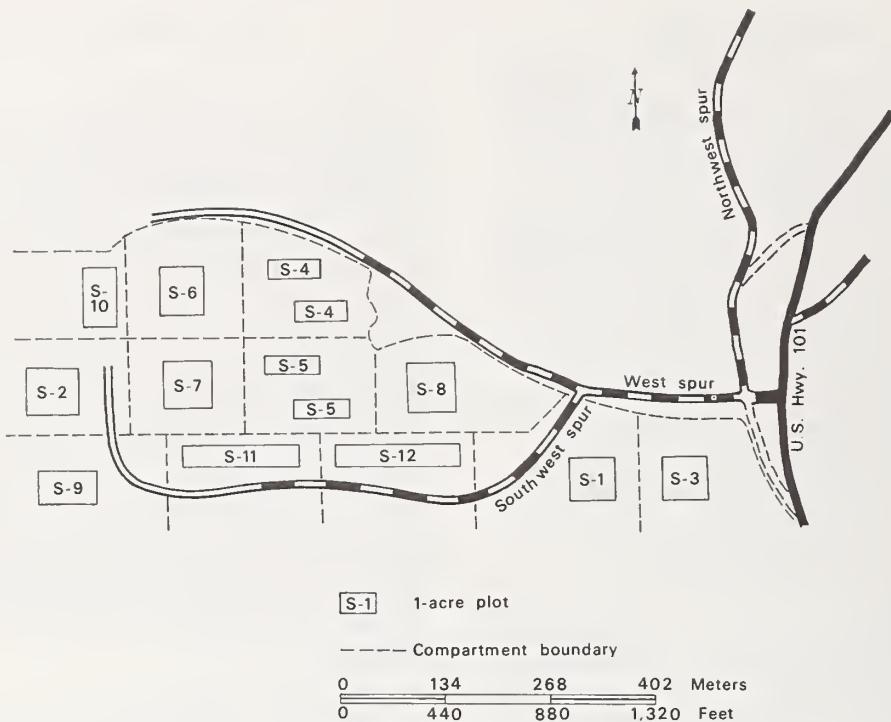


Figure 1.--Map of compartments and central acres containing milacre plots, shelterwood study area, Hemlock Experimental Forest.

TREATMENTS

Treatment was defined as number of residual overstory trees (6-inch d.b.h. and larger) per acre. A three-stage shelterwood cut was planned. The first and second cuts in 1960-61 and 1964-65, respectively, resulted in the following stand characteristics:

Plot	Trees per acre		Basal area per acre	
	1960-61	1964-65	1960-61	1964-65
(Square feet)				
S-1	328	175	210	137
S-2	185	110	235	158
S-3	135	97	185	159
S-4	134	65	196	117
S-5	145	62	121	64
S-6	90	40	162	74
S-7	54	27	84	73
S-8	58	18	82	44
S-9	68	40	59	52
S-10	64	21	72	36
S-11	32	17	38	43
S-12	42	20	48	19

Basal area per acre is the average of

estimates made at each milacre plot with a 30 basal-area-factor prism. This average, hereafter, is referred to as BA30. The third cut was in 1968 and 1969.

The range in stand and forest floor conditions as of 1964 is illustrated in figure 2.

The second cut was originally scheduled to begin in 1965, but sufficient windfall occurred in a severe windstorm in October 1962 to advance this cut to 1964 to prevent decay losses. Some treatments were not cut until 1965. Thus, the interval between the first and second cuts for the various treatments varied between 2.5 and 4 growing seasons. The second cut reduced numbers of trees by approximately one-half. The third cut was final overstory removal.

Harvesting of the first cut in 1960-61 was by crawler tractor. The harvesting in 1964-65 and 1968-69 was by rubber-tired skidder (fig. 3).

*Figure 2.--*Dense stands like A have a forest floor like B.
More open stands, C, encourage seedling establishment, D.
The most open stands, E, support a mat of vegetation, F.





Figure 3.--Logging on the shelterwood study area, 1964.

Results

This study was designed for a three-stage shelterwood harvest. The primary emphasis in this section, therefore, will be on results after completion of these three stages. We recognize, however, that in practice, most land managers will opt for a two-stage harvest. Therefore, after looking at regeneration by 1971, 2 years after the final cut, we will examine the status of regeneration after the second cut, pretending that we are looking at results of a two-stage harvest. A real two-stage harvest, however, would result in more slash and in more skidding than occurred at the second cut in this study. These factors would tend to lower somewhat the number of seedlings compared with the numbers that actually occurred after the second cut.

Finally, we will tell what happened to the overstory and to lesser vegetation.

The number and distribution of hemlock seedlings needed for a new stand depend on management objectives. Current practice in precommercial thinning of western hemlock is usually to thin to a 12- by 12- (3.6- by 3.6-m) or a 10- by 10-foot (3.0- by 3.0-m) spacing, 302 and 436 trees per acre (746 and 1,077 per ha), respectively. Theoretically, those stocking levels would result if 30.2 or 43.6 percent of the milacre plots are stocked with one established seedling. Practically, many plots will have more than one seedling. Some extra seedlings will be needed, however, because mortality will occur. Some seedlings will become established on poor microsites and grow slowly, and some will be genetically inferior. Each manager must set his own stocking objectives.

Hemlock regeneration over 0.3 foot (9 cm) tall is reported here as a percent of milacre plots stocked and as number

of seedlings per acre. Numbers after 1964 are conservative, particularly at the higher levels, because of the difficulty of mapping more than 10 seedlings on a milacre quadrant (one-quarter of a milacre). Numerous quadrants eventually had more than 10 seedlings.

REGENERATION BY 1971, 2 YEARS AFTER THE REMOVAL CUT

Number of Seedlings

At the beginning of the experiment, hemlocks averaged 2,220 advance regeneration stems per acre (5,485 per ha) over all treatments. The first cut destroyed many of these, leaving 650 per acre (1,606 per ha) 1 year later. Thereafter, seedling numbers decreased gradually from natural mortality and logging damage. In 1971, at the end of the experiment, 280 seedlings per acre (690 per ha) survived, 13 percent of the original number. The decrease in number of seedlings did not seem to be correlated with overstory density.

Hemlock postlogging regeneration was prolific (fig. 4). Many small seedlings became established the first year after the first cut. Of these, an average over all treatments of 440 per acre (1,087 per ha) already exceeded the minimum measurement height of 0.3 foot (9 cm). By 1964, there were over 12,200 hemlock seedlings per acre (30,200 per ha). After the second cut, the number was down a little more than 6 percent to about 11,500 per acre (28,400 per ha). Just before the final removal cut in 1968-69, the number of seedlings had increased to about 17,000 per acre (42,000 per ha). The final harvest did not destroy many seedlings, and the number had increased to over 18,500 per acre (45,700 per ha) by the final measurement in 1971.

**A****B****C**

Figure 4.--Shelterwood treatment S-12 was the poorest environment for seedling establishment. The first cut left an overstory basal area of 48 square feet per acre ($11 \text{ m}^2 \text{ per ha}$). The second cut, after four growing seasons, reduced basal area by one-half.

(A) Eight growing seasons after the first cut and just before the final cut, the average height of the tallest postlogging seedling per milacre was 4.0 feet (1.2 m).

(B) One growing season after the final cut there were 6,270 postlogging seedlings per acre (16,500 per ha), and the average height of the tallest seedling per milacre was 4.5 feet (1.4 m).

(C) Three growing seasons after the final cut there were 8,500 postlogging seedlings per acre (21,000 per ha), and the average height of the tallest seedling per milacre was 6.4 feet (2.0 m).

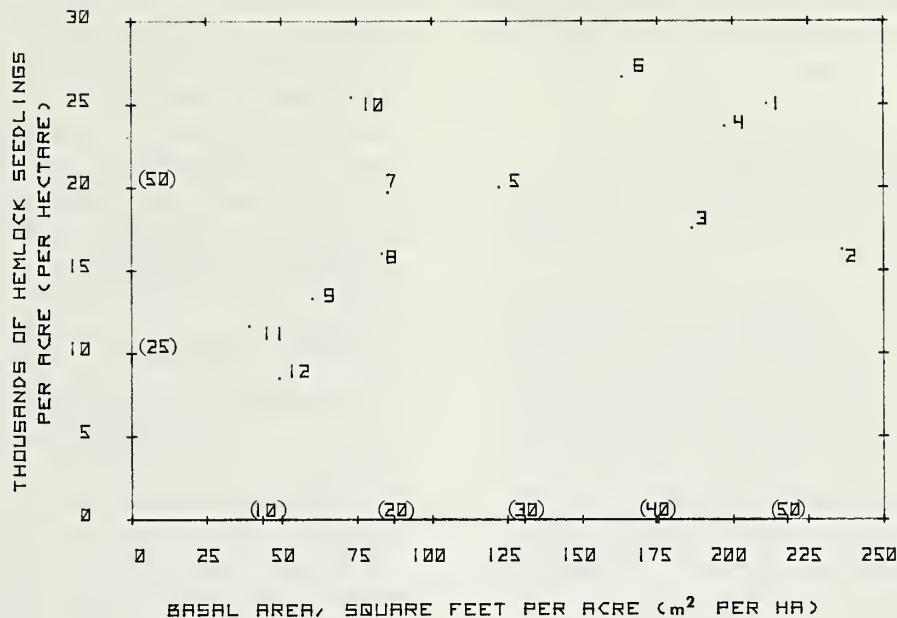


Figure 5.--Number of postlogging hemlock seedlings in 1971 by residual basal area per acre after 1960-61 cut, by treatment number.

The number of seedlings increased with residual basal area per acre of the overstory, then trended downward under the densest overstories (fig. 5). This relationship was not evaluated statistically because of bias resulting from not counting more than 10 seedlings per milacre after 1964. Fewer seedlings were established on the more open areas, probably because of more slash covering acceptable seed beds and more brush competition. Also, many seedlings were killed during germination and early establishment, presumably by solar radiation. The greatest number of seedlings became established under the moderate overstories of 100 to 190 square feet of basal area (23 to 44 m^2 per ha).

But even the lightest overstory of 38 square feet per acre (8.7 m^2 per ha) basal area had about 11,650 seedlings per acre (28,800 per ha)--too many for intensive management without costly precommercial

thinning. The shelterwood system did too good a job of seedling establishment. This might have been expected, because clear-cutting, which provides no overstory shelter, also frequently leads to overstocking. It might have been better if more seedlings had been destroyed during overstory removal.

One might expect several factors besides overstory density to influence seedling density. These include seed supply, logging damage, seed bed conditions, and illumination as influenced by both the overstory and lesser vegetation.

SEED SUPPLY

Apparently, more than adequate seed fall occurred in all treatments to satisfy regeneration opportunities that occurred. Average annual seed fall in the most open stand averaged nearly 1,000,000 viable seeds per acre (2,471,000 per ha) per year.

Average annual viable seed production per acre through the seed year 1965-66 (fig. 6) is related to BA30 as follows:

$$\begin{aligned} \text{Number viable seeds (thousands)} \\ = 904 + 5.071(\text{BA30}) \\ (\text{r} = 0.82 \text{ with } 10 \text{ degrees of freedom,} \\ \text{Sy.x} \doteq 239.7) \end{aligned}$$

There is no suggestion of curvilinearity in the data, indicating that a square foot of basal area in lower crown class trees supported as much seed production as in upper crown class trees. Below about 150 square feet per acre ($370 \text{ m}^2 \text{ per ha}$) of residual basal area, stands contained mostly dominant and codominant trees. Above this level, increased residual basal area meant more intermediate and suppressed trees in the stand.

LOGGING DAMAGE

Logging alone did not significantly reduce

average density of seedlings. Seedlings destroyed during logging were mostly in main skid roads which cover a small percentage of the total area. Off the skid roads, yarding only a turn or two of logs over a small, limber seedling often mashed it into the duff or mud, but usually it returned to an erect position by the end of the next growing season.

SEED BED CONDITIONS

Condition of seed bed was not a significant factor in determining numbers of seedlings, perhaps because of the difficulty of quantifying the data, but more probably because average seed bed conditions did not differ significantly among treatments. Further, seed bed effects were strongly influenced by variations in density of the overstory. Deep slash, of course, strongly inhibited seedling establishment.

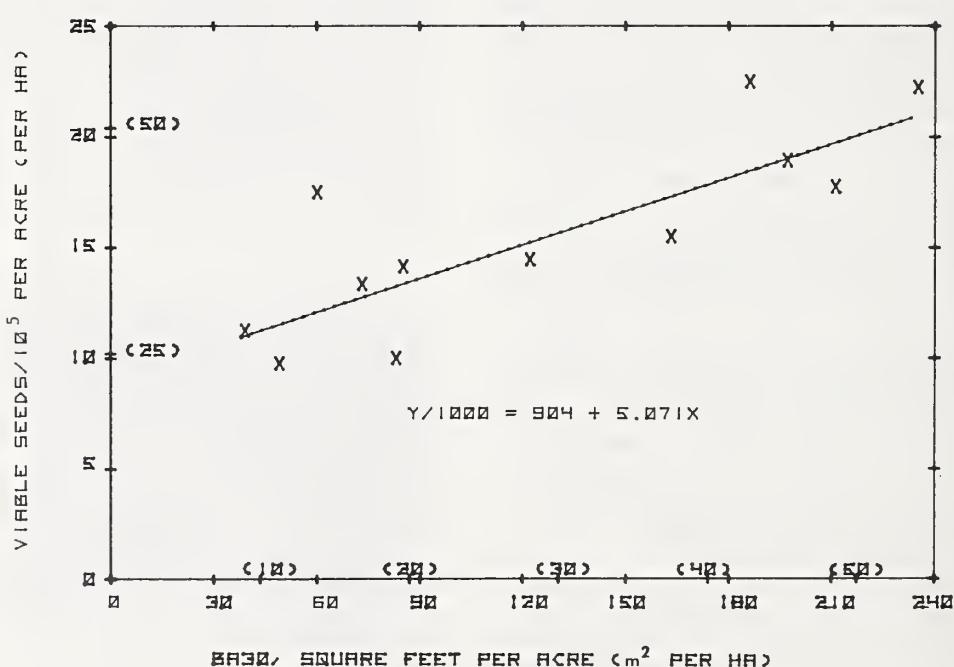


Figure 6.--Average annual (1961-65) viable seed production relative to residual basal area (BA30).

ILLUMINATION

Measurements of solar illumination showed that high numbers of seedlings occurred on some plots receiving only about 2 percent of full sunlight. Other factors, such as soil moisture and soil-air interface temperatures, probably interact with and modify the effects of illumination. Certainly, regeneration will not be suppressed by lack of illumination under any shelterwood stand which results from cutting at least one-third of the original basal area.

Stocking

Before any logging, 39 percent of the milacre plots under the 60-year-old stand were already stocked with at least one advance hemlock seedling. Disturbance during the first cut destroyed many of these seedlings, reducing the stocking 1 year later to 19 percent of the plots. Thereafter, stocking was reduced gradually by logging and natural mortality until only 10 percent of the milacre plots were stocked with advance regeneration at the end of the experiment. The range among the treatments was 0 to 24 percent. The decrease in stocking over time did not seem to be correlated with overstory density; a regression of final stocking on overstory density after the seed cut was not significant.

Postlogging regeneration over 0.3 foot (9 cm) tall was found on 12 percent of the milacre plots 1 year after the first cut. Stocking increased rapidly to an average of 80 percent over all treatments after the fourth growing season, then increased more slowly to 94 percent at the end of the experiment. The range among treatments was 84 to 100 percent of milacres stocked. There was no significant relationship between overstory density, expressed as basal area per acre after the first cut,

and percent of milacres stocked with postlogging regeneration.

Height Growth

In 1960, height of the tallest advance seedlings under the dense uncut stand averaged 1.5 feet (47 cm) tall. At the end of the experiment in 1971, they averaged 7.4 feet (226 cm) tall. All three cuts destroyed some seedlings. Enough survived on eight treatments, however, to calculate regressions showing trends in total height with time and with overstory basal area. Since measurements were repeated on the same plots, statistical tests of significance are not valid and the regressions show general trends only. There was a drop in height after the first cut. This resulted from a reduction in average height when the tallest seedling on a milacre was destroyed during logging and replaced by a shorter one. After subsequent timber cutting, height growth exceeded losses due to replacement on the milacres, and the curves trended upward. Generally, height growth was greater on the treatments with less overstory density (fig. 7). Obvious exceptions to this trend are treatments 3 and 7, with 7 appearing lower than it should, and 3 appearing higher. Tallest seedlings on treatment 7 had much mortality, while those in treatment 3 experienced little, if any, mortality. The difference in height points out a potential advantage in preserving advance regeneration. Even though seedlings in treatment 7 were growing faster than those in treatment 3 at the end of the study, they were still about 2 feet (60 cm) shorter. After the final cut, height growth should be about the same in all treatments, so seedlings in treatment 7 probably will never catch up to those in treatment 3.

Postlogging regeneration reached the minimum measurement height of 0.3 foot (9 cm) soon after the first cut. As with advance regeneration, height growth

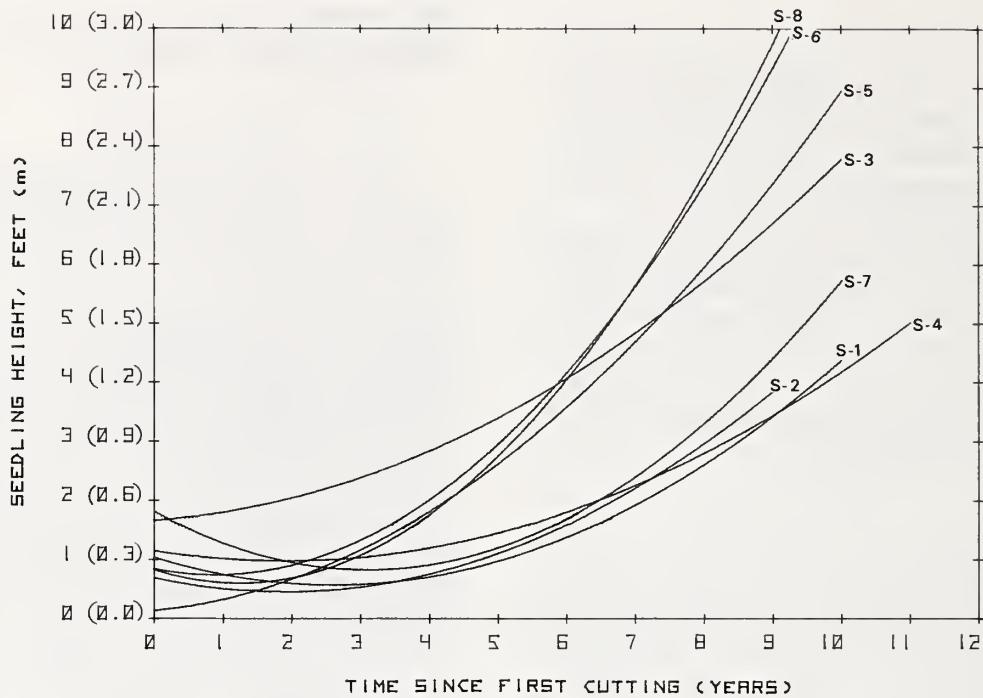


Figure 7.--Influence of time after cutting on heights of advance regeneration, tallest seedling per acre, by treatment number.

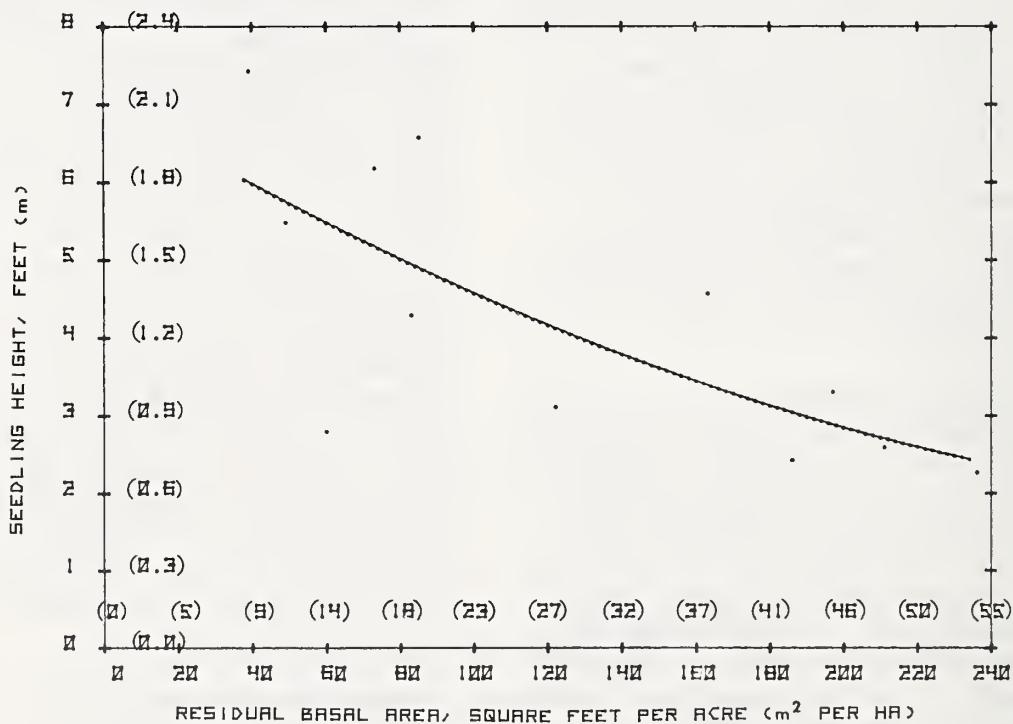


Figure 8.--Relationship of height of postlogging regeneration to overstory basal area per acre, 10 years after the first cut.

generally was greater on treatments with less overstory density (fig. 8 and 9).^{3/}

Where marked deviations from the trend in figure 8 occurred, they could be attributed

Figure 9.--Height of post-logging hemlock regeneration was greater on treatment areas with low overstory density.

(A) Treatment S-1. Basal area of the overstory after the first cut was 210 square feet per acre ($48 \text{ m}^2 \text{ per ha}$). Average height of the tallest seedling per milacre 10 growing seasons later was 2.7 feet (0.8 m).



(B) Treatment S-11. Basal area of the overstory after the first cut was 38 square feet per acre ($8.7 \text{ m}^2 \text{ per ha}$). Average height of the tallest seedling per milacre 10 growing seasons later was 7.6 feet (2.5 m).



to differences in competing vegetation on the plots. Average height of the tallest seedling per milacre at the end of the experiment in 1971 was 4.6 feet (141 cm), about two-thirds as tall as the advance regeneration.

^{3/} The curve depicted in figure 8 is described by the equation:
 $\text{Height (ft)} = 7.1 - 0.0291(\text{BA}30) + 0.00003948(\text{BA}30)^2$
 $r = 0.727$ with 9 degrees of freedom
($p < 0.05$)

REGENERATION BY 1965— SIMULATING A TWO-STAGE HARVEST

Because logging costs would be less, some land managers may want to use a two- rather than a three-stage harvest. Looking at regeneration after the second cut gives some idea how a two-stage shelterwood would work.

Number of Seedlings

After the second cut, the lowest number of postlogging seedlings was found in the stands which were densest after the first cut (fig. 10). The first cut in these stands approximated a moderate thinning, leaving the residual overstory dense enough to suppress most germinants. Numbers of seedlings increased as overstories became less dense and finally declined under the most open stands. For holding down precommercial thinning costs, building up stand density toward the end of a rotation

might be a rational course of action.

The equation in figure 10 implies that steeper slopes have fewer seedlings than gentler slopes in this study where average slopes ranged from 0 to 30 percent. No reasons for this relationship are apparent, and it may be due to a concentration of steeper slopes at the extremes of treatment.

Stocking

Summing up the regeneration characteristics of these shelterwood treatments as of 1965, seedling density and stocking are at least adequate by almost any criterion. At the extremes of treatment, about 16 percent of the milacre plots were unstocked. This percentage of unstocked plots might be expected with over 1,000 seedlings per acre (2,500 per ha), considering that some clumpiness is bound to occur.

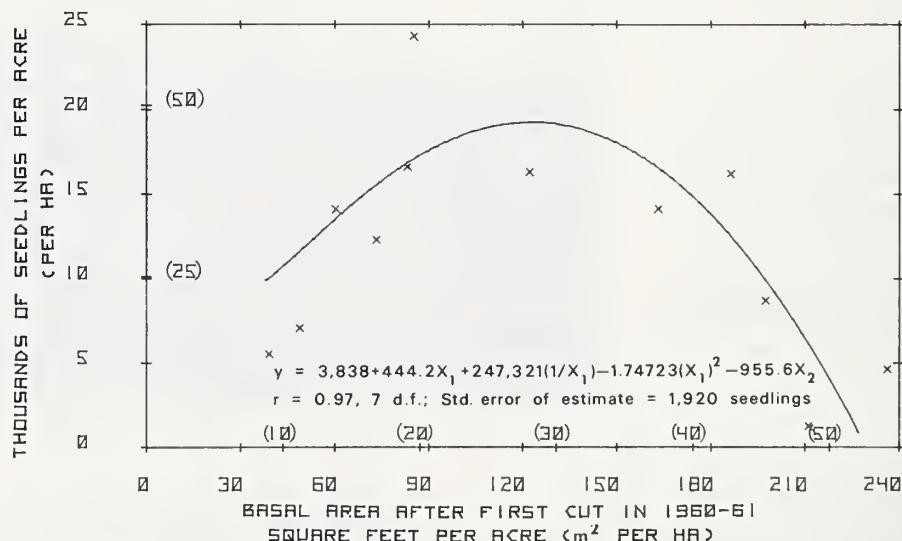


Figure 10.—Number of established seedlings 4 to 5 years after the first cut by residual basal area (X_1) and for average slope (X_2) of 15.5 percent.

TREATMENT EFFECTS ON OVERSTORY CHARACTERISTICS

Windthrow

Windthrow due to the October 1962 windstorm was remarkably light, considering that western hemlock has been observed to be a windthrow-prone species (Ruth and Yoder 1953), yet it was heavy enough that the second cut was advanced 1 year. One might expect all newly exposed trees, some almost completely isolated, to be blown down by a record windstorm. However, average basal area loss on the 1-acre plots was only 13 percent, ranging from 0 to 39 percent. Losses generally were heavier on the more open stands, but topography appears to have strongly modified the effects of cutting intensity. The worst loss (39 percent) occurred in a highly exposed area with 107 square feet of basal area per acre ($24.5 \text{ m}^2 \text{ per ha}$). Another area, relatively protected and with only 65 square feet of basal area ($15 \text{ m}^2 \text{ per ha}$), lost only 4 percent of its basal area. Losses in other areas that were cut to densities of less than 65 square feet per acre ($14.9 \text{ m}^2 \text{ per ha}$), but with moderate exposures, averaged about 25 percent.

Other than mortality from the 1962 storm, windthrow mortality has been light in all treatments. Almost invariably, it was associated with damage to root systems by logging machines.

Overstory Growth

Individual trees, and thus stands, do not appear to have responded to increased growing space by increasing total cubic volume growth relative to trees in uncut stands. Dendrometer measurements (see appendix, "The Overstory") were analyzed by covariance, with residual basal area as the independent variable

and with initial d.b.h. classes defining treatment groups. There was no significant difference between treatments as to individual tree volume. Evidently, drastic release stimulated basal area growth but decreased height growth by as much as 80 percent.

What this implies is that stand growth in these shelterwood areas has been approximately proportional to the number of residual trees. The predictions of volume growth of the more open shelterwood treatments, based on a local volume table in an earlier report (Williamson 1966), are probably overly optimistic.

LESSER VEGETATION DEVELOPMENT

Crown cover of lesser vegetation averaged 32 percent during the study. This average does not include hemlock crowns, which formed a closed forest overstory approximating 100-percent cover in the beginning of the experiment and which was removed in three stages. Then, as young seedlings, hemlock was again on the way to a closed canopy. Major interest is in relationships between lesser vegetation and hemlock seedlings. Since tree seedlings became established in profusion, an average 32-percent cover of competing vegetation might have affected seedling establishment but obviously did not prevent it.

Canopy coverage of lesser vegetation increased gradually with time (fig. 11) and concurrently with growth of hemlock seedlings (fig. 7). There was a general inverse relationship between overstory and understory density. Treatments with an open forest overstory generally had more dense understory, an expected response to greater sunlight. If anything, the relationship was more variable than expected, apparently due to differences in understory plant cover at the beginning of the experiment. For example, the plot (S-9) that was reduced to 59 square feet of basal area per acre

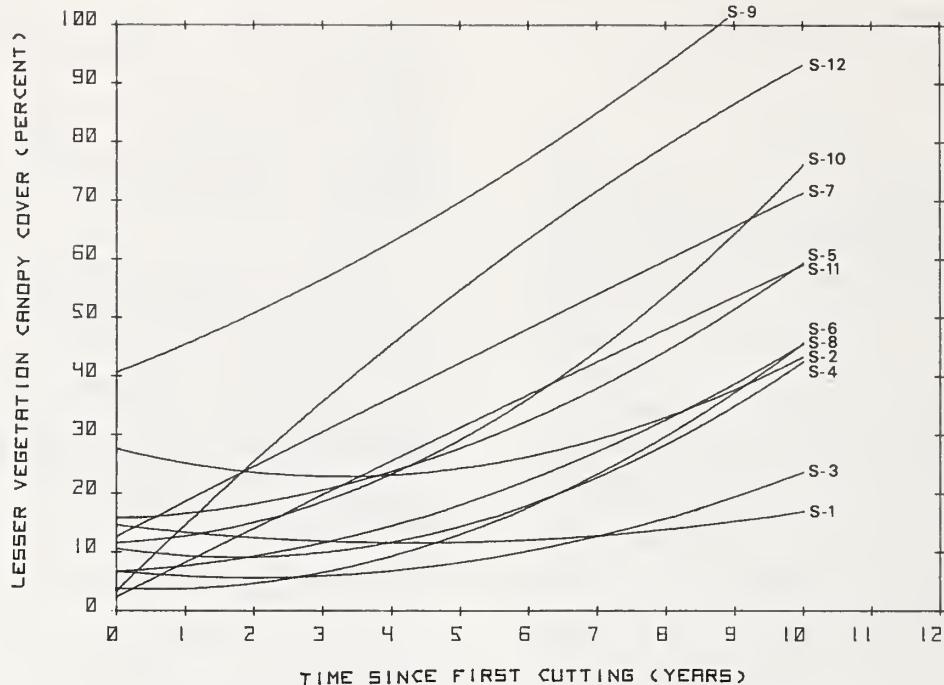


Figure 11.--Relationship of lesser vegetation canopy cover to number of years after first cut, by treatment.

(16 m^2 per ha) by the first cut had 54 percent crown cover of understory vegetation at the beginning of the experiment, more than any other plot. This understory persisted and increased after the shelterwood cuttings. The overall average for this treatment was 74 percent cover compared with the general average of 32 percent. This much competition apparently affected the height growth of hemlock seedlings. The average height of the tallest seedling per milacre was only 3.2 feet (0.98 m), a height similar to treatments that had much more overstory density (fig. 8).

As can be seen in figure 11, lesser vegetation was of no consequence after the second cut, except for two plots (S-9 and S-12) where lesser vegetation was well established before any cutting. Small portions of these two stands had poorly stocked overstories to begin with.

When shrubs and herbs were considered separately, again there was a tendency for treatments with the least basal area per acre in the overstory to have a greater crown cover of shrubs and herbs. There was some tendency for shrub cover to dip down as survivor species faded out, then to increase as invading species became established. Herbs increased rapidly, then leveled off. But this did not occur on all treatments (figs. 12 and 13).

Individual plant species observed on the plots are listed in the appendix. Of these, only five became major components of the ecosystem in terms of canopy coverage. The others generally remained below 10 percent on all treatments.

Salmonberry (*Rubus spectabilis* Pursh), a major competitor elsewhere (Ruth 1970), was present here on all areas and did overtop

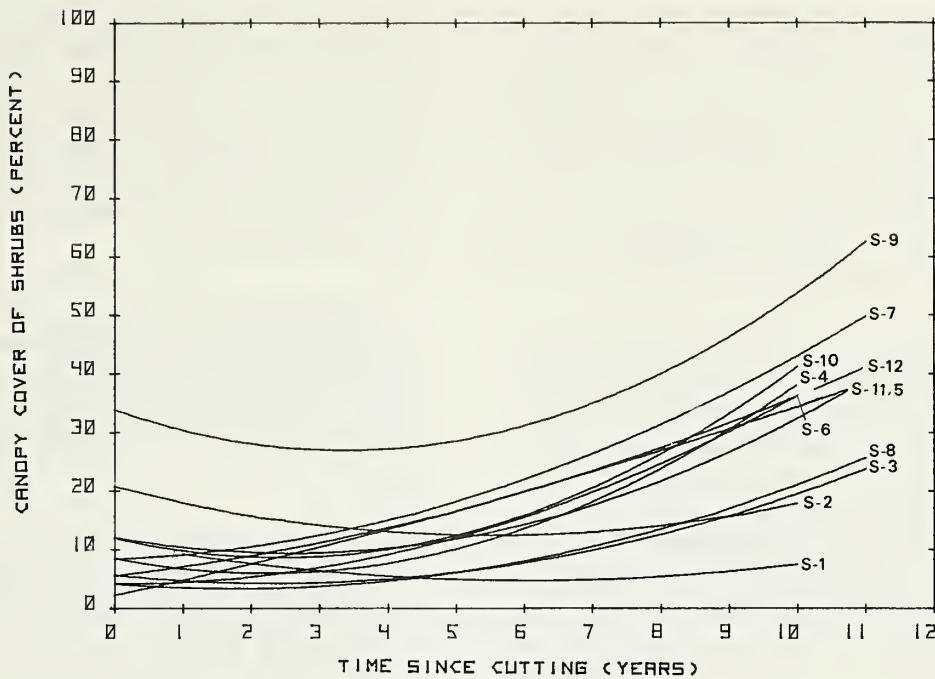


Figure 12.--Influence of time since cutting on canopy cover of shrubs, by treatment.

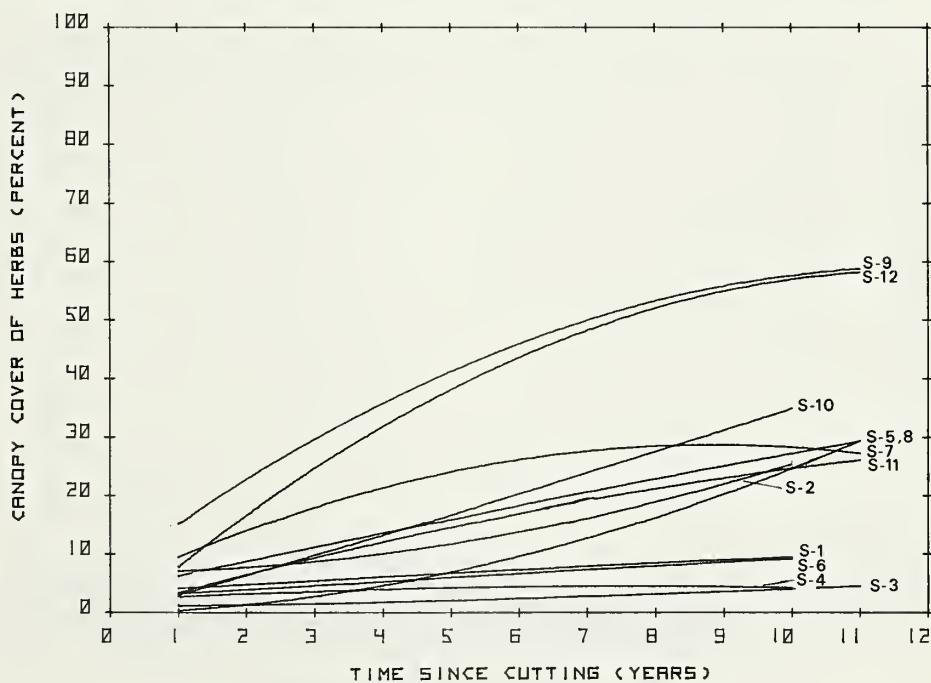


Figure 13.--Influence of time since cutting on canopy cover of herbs, by treatment.

and suppress some hemlock seedlings. Before logging, however, salmonberry was observed on only 3 of the 12 treatment areas; and canopy coverage on these was only 0.1 percent. After logging, salmonberry crowns spread slowly, the plants probably originating from seed rather than sprouts. This gave hemlock seedlings a better chance to compete (fig. 14).

Vine maple (*Acer circinatum* Pursh) was observed on all but one treatment area at the beginning of the study. There were no strong trends to increase or decrease over the study period (fig. 15). Trailing blackberry (*Rubus ursinus* Cham. & Schlecht.) increased only moderately in response to the cutting treatments and, on one treatment area, apparently declined (fig. 16). This was the 59-square-foot basal area per acre (13.5-m^2 per ha) treatment with the most vegetation. Apparently, taller plants overtopped and suppressed the blackberry. Salal (*Gaultheria*

shallon Pursh) was heavy on this same treatment area and increased substantially here and on a few other areas (fig. 17). Bracken fern (*Pteridium aquilinum* (L.) Kuhn. var. *pubescens* Underw.) encroached rapidly on only two treatment areas (fig. 18), those which had poorly stocked portions before the first cut.

Red alder, often a severe competitor overtopping hemlock seedlings (Ruth 1965), was only a minor species here. It did appear, mostly on exposed mineral soil along skid roads, but had little overall effect.

In general, competition from lesser vegetation was not serious in the study area. Hemlock seedlings became established between other plants or came up through them. Many were still overtopped at the end of the study. With too many hemlock seedlings, this may be taken as a favorable circumstance.

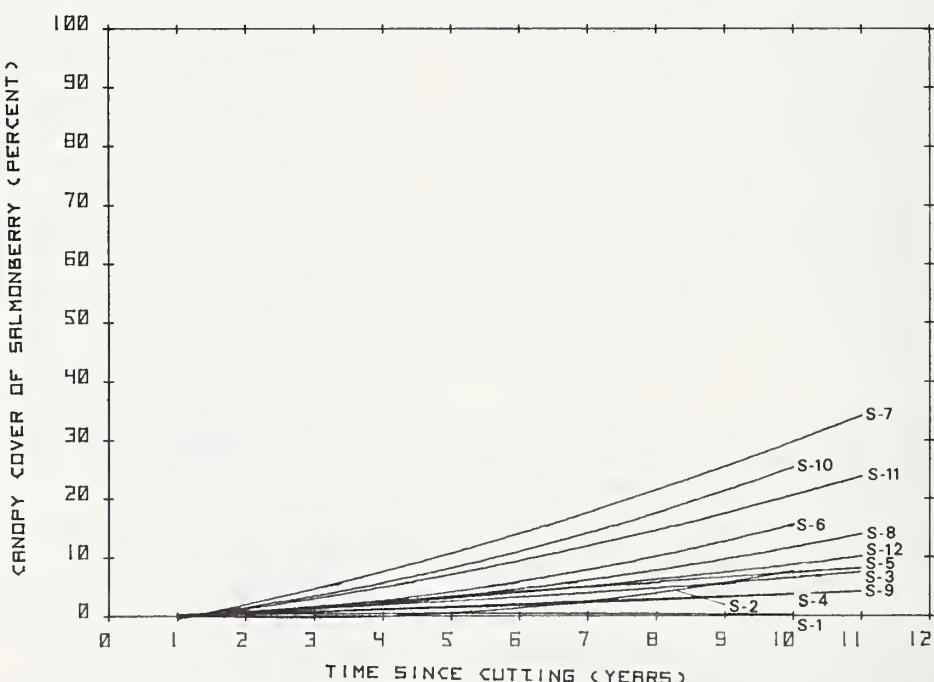


Figure 14.--Influence of time since cutting on canopy cover of salmonberry, by treatment.

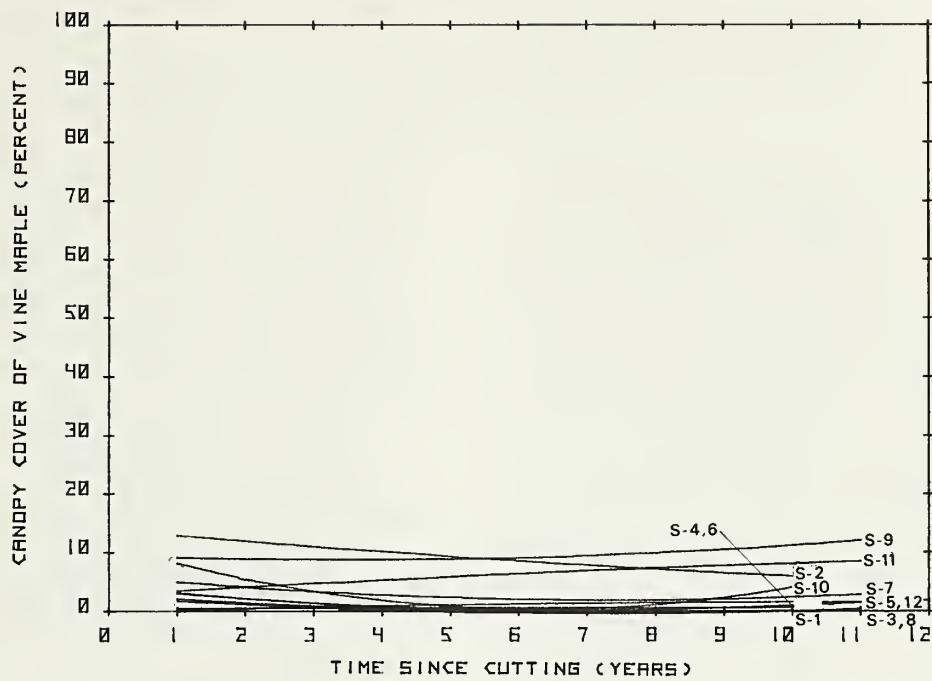


Figure 15.--Influence of time since cutting on canopy cover of vine maple, by treatment.

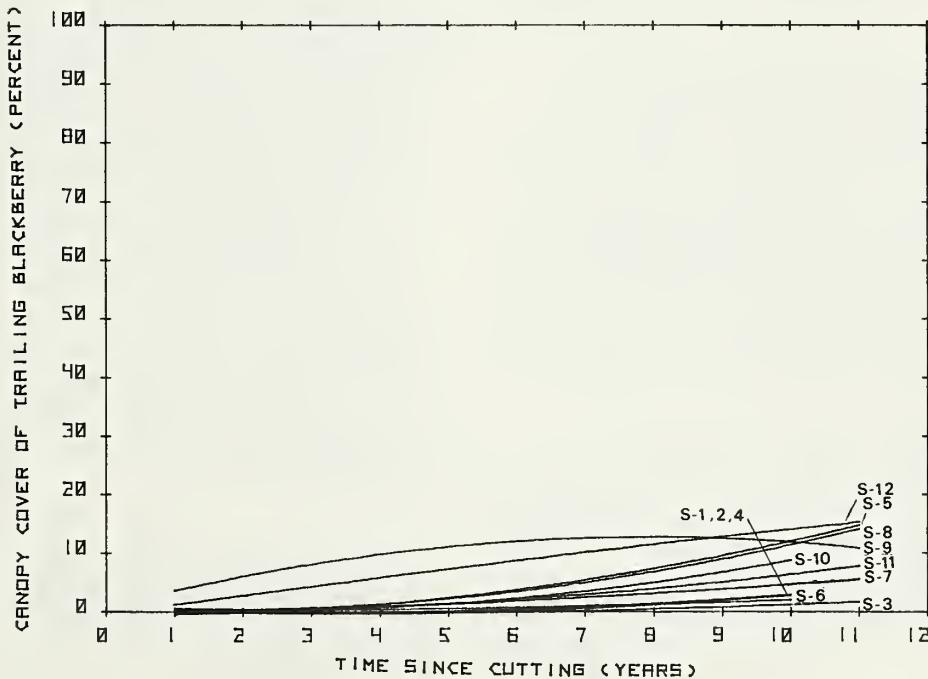


Figure 16.--Influence of time since cutting on canopy cover of trailing blackberry, by treatment.

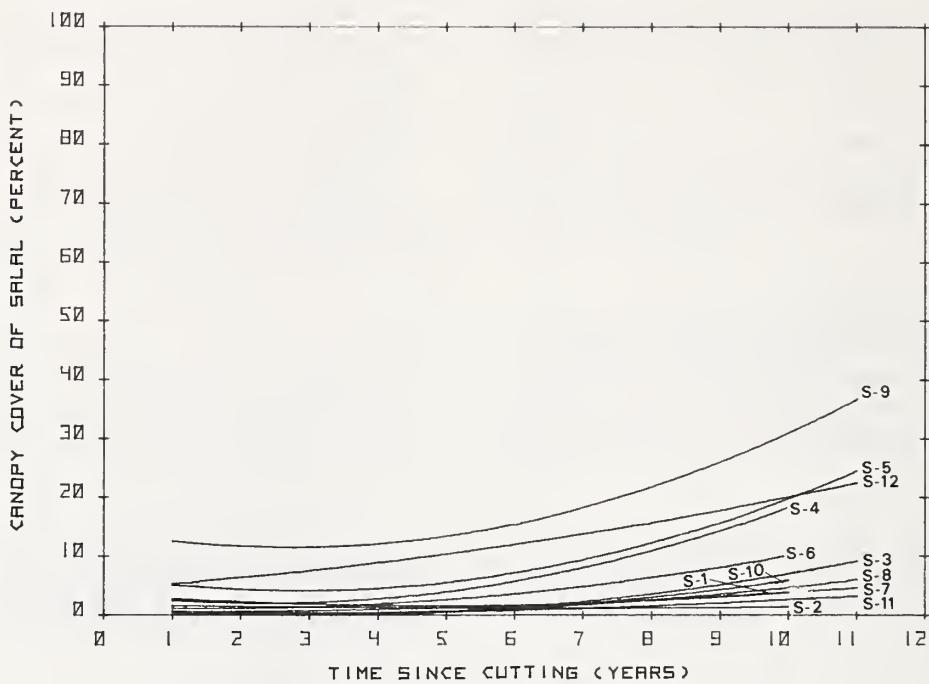


Figure 17.--Influence of time since cutting on canopy cover of salal, by treatment.

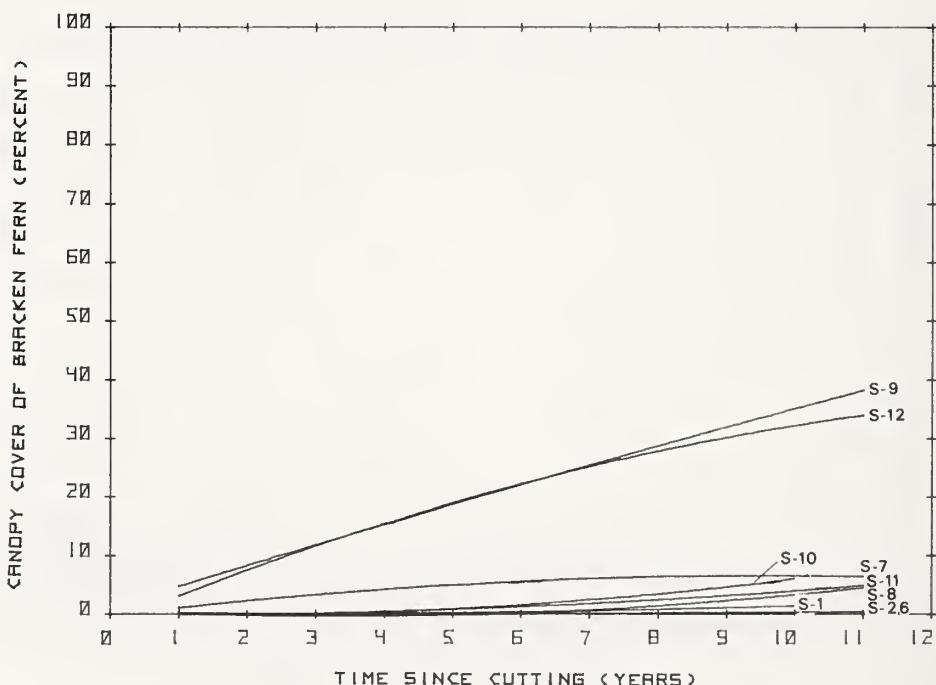


Figure 18.--Influence of time since cutting on canopy cover of bracken fern, by treatment.

Discussion and Conclusions

The silvicultural goal of harvest cutting is to create proper conditions for establishment of a new timber stand. Shelterwood cutting in western hemlock, as applied here, did this--probably too well; there were too many seedlings. There will be intense competition between them beginning at an early age, and cost of precommercial thinning will be high. Treatments leaving the least basal area per acre after the first cut had the fewest seedlings at the end of the experiment, and these seedlings tended to be taller. Yet there was enough for selection of better trees. These light overstories were almost clearcuts, and we might speculate that clearcutting with an adjacent seed source would have provided still fewer and taller seedlings. Logging costs would have been less because it would have been more efficient to remove all the timber at once.

Conversely, after the second cut, we saw that the stands which were densest after the first cut had even fewer seedlings, though still plenty for selection of better trees. The regeneration period, in addition to being two stages instead of three, could be shortened, cutting down further on seedling numbers. This suggests, again, the adequacy of clearcutting. We expect that, under conditions similar to those of the study area, both clearcutting and shelterwood harvesting will generally provide adequate regeneration throughout the coastal hemlock zone in Oregon and Washington. Shelterwood harvesting promises surer regeneration success in brush-threatened areas.

Shelterwood harvesting offers the land manager an opportunity to cut enough trees from a stand to establish regeneration but to hold most of the stand in anticipation of greater returns from a rising market. This study, however, was biologically

oriented; and results are limited accordingly. The forest manager must apply the biological data to his particular economic situation.

Shelterwood cutting has been proposed as a means of controlling brush competition and favoring hemlock seedlings. Brush problems were generally not serious in the study area; but even where lesser vegetation was well established before the first cut, more than adequate numbers of hemlock seedlings survived and grew, albeit at a slower rate than that of seedlings in situations where lesser vegetation was initially sparse. We expect that shelterwood secured regeneration in these brush-threatened areas primarily through sheer weight of seed fall, and that brush probably would have captured these areas after they were clearcut. Lesser vegetation was heavier in more open treatments and apparently did affect the numbers of seedlings. But there were too many seedlings anyway and seedlings that came through generally tended to be taller.

Of all the understory species present, none "exploded" or quickly dominated a treatment area. The main problem of competition was on the areas having the most vegetation to start with. We believe that problems from competition can be recognized in advance of cutting and dealt with by appropriate harvesting, residue management, and vegetation control techniques (Ruth 1956, Cramer 1974).

This study area received no site preparation, and such treatment does not seem necessary under these stand and site conditions. There was no problem in securing regeneration without site preparation, and lack of such preparation retains maximum benefits to forest soil (Ruth 1974, Rothacher and Lopushinsky 1974).

Shelterwood cutting has been proposed

as an esthetically viable alternative to clearcutting. Depending on rate of overstory removal, the new stand can be grown to any selected height before removal cut. In this study, heights of the tallest seedlings ranged from about 2 to 8 feet (0.6 to 2.4 m) depending on the density of the overstory (fig. 8). Stumps were well hidden on some treatment areas, not on others; and the appearance varied accordingly. If an overstory is removed promptly after initial seedling establishment, seedlings 3 inches (9 cm) tall for example, the area will look much like a clearcut. However, seedlings will already be established and should grow rapidly to overtop stumps sooner than clearcutting with no seedlings present. If regeneration can be left long enough so that a two-storied stand develops, the overstory may be removed in stages with little more environmental impact than commercial thinnings. Environmentally, the shelterwood system provides wide flexibility. It should find increasing acceptance in areas where the appearance of the forest is particularly important.

The timber stand studied here grew for 60 years before cutting began. That this low level of management is unlikely in the future has important implications. The lighter first cuts resulted in prolific regeneration. The same can be expected after commercial thinning. Surely there will be exceptions; but we think this means, in general, that intensive management through thinning will result in seedling establishment in the understory.

This meets the definition of shelterwood cutting in that seedlings are established under the protection of the overstory. Such areas might be termed accidental or unplanned shelterwood. It appears that whether a harvesting system is called clearcutting or shelterwood cutting may be somewhat arbitrary and may

depend on whether or not the establishment and utilization of advance regeneration are part of a planned silvicultural system. Whatever the terminology, the presence of advance regeneration is increasing rapidly with the spread of commercial thinning in hemlock stands. Increasing use of the last commercial thinning to encourage regeneration is a logical development. Once regeneration is established, decisions of the landowner will concern the esthetic question of whether to extend overstory removal to get more height on the regeneration, and techniques of removal that might control spacing of seedlings.

Two research needs regarding the shelterwood system are particularly urgent. Economic analyses are needed to compare the shelterwood system with clearcutting. Second, techniques need to be developed to control and limit seedling establishment. Control of stocking with powersaws or chemicals does this but is costly; and by the time it becomes practical, crop trees already have been held back by intensive competition. Perhaps log yarding techniques for removing the overstory can be developed to destroy seedlings, yet leave a sufficient density of well-distributed seedlings.

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Appendix

DATA COLLECTION AND ANALYSIS

The Overstory

Diameters at breast height of residual trees were recorded after the 1960-61 cut, the 1964-65 cut, and before overstory removal in 1968-69. Diameters of trees cut in 1964-65 were estimated under the assumption that a cut tree grew the same as a residual tree that had the same initial (1960-61) diameter. These diameters were used to calculate growth between the first and second cuts.

A local volume table,^{1/} derived from total height and d.b.h. measurements in similar stands throughout the Experimental Forest, was used to estimate volume per acre at each measurement.

Many well-released trees grew remarkably well in basal area during the period between first and second cuts. Thus, the local volume table indicated considerable volume increment. Complete stem measurements, by Barr-Stroud^{2/} optical dendrometer, were made in 1967 on a sample of trees, primarily to see if these trees were being

buttressed in the lower portions of their stems and thus biasing volume estimates.

Complete stem measurements were recorded for one to four trees (average three) in each of the initial (1960-61) 12-inch (30-cm), 16-inch (41-cm), and 20-inch (51-cm) d.b.h. classes in each of six treatment areas ranging from dense to open and in an uncut stand in an adjacent thinning study. There were 15 measured trees in each d.b.h. class. Our assumption was that trees with similar d.b.h. before treatment (1960-61) then exhibited no more than the usual random variation in cubic volume found in uncut stands. Thus, any statistically significant differences between treatments by 1967, in cubic volume per tree for any diameter class, should reflect treatment effects; and volume growth estimates based on the local volume table could be affirmed or rejected.

Regeneration

Locations of seedlings, both advance and postlogging, 0.3 foot (9 cm) tall or more on the milacre plots were mapped and counted by milacre plot quadrants (one-quarter of a milacre plot) (fig. 19) by the technique described by Neebe and Boyce (1959). Advance regeneration included saplings up to 6-inch (15.2-cm) d.b.h. Initially, sapling-size advance regeneration was distributed throughout the study area. However, most of it was destroyed during logging.

Through the 1964 measurement, postlogging seedling density was generally low enough that all seedlings could be mapped. For 1965 and after, seedling density generally was so great that individual seedlings could not be mapped. Mapping was limited to 10 seedlings per quadrant. We thought consideration of numbers greater than 10 per quadrant was moot because this maximum indicated severe overstocking.

^{1/} Volume of trees with both d.b.h. and height measurements were read from table 6 of "Volume tables for permanent sample plots," USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1953.

^{2/} Use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Illumination



Figure 19.--Using a sector board to identify seedlings by azimuth and distance from a milacre plot center.

Greater overstocking is not liable to be of practical significance. The height of the tallest seedling per milacre quadrant was recorded at each measurement.

Lesser Vegetation

Canopy density for each species of lesser vegetation on each milacre plot was estimated by methods proposed by Daubenmire (1959). Total coverage was obtained by adding percentages for individual species. In cases of layered vegetation, the total could exceed 100 percent. Nine field estimates of regeneration and lesser vegetation were made during the 12-year study. Common and scientific names of vascular plants found on the study area are listed on page 25.

Illumination was measured at the center of each milacre plot, for 1 day in mid-August 1964. The samples were taken at 3 inches above ground to include most lesser vegetation canopy effects as well as those of the overstory. Plot measurements were expressed as percentages of simultaneous measurements made under open sky. Illumination was measured with an anthracene-in-benzene solution, according to principles described by Dore (1958) and procedures described by Rediske et al. (1963).^{3/} Percentages obtained were assumed to be reasonable estimates of photosynthetically active light reaching the plots (Vezina and Boulter 1966).

Slash

Depth of slash on each milacre plot was recorded only as being greater or less than 1 foot (0.3 m).

Milacre Plot Characteristics

Aspect was recorded to the nearest octant and percent slope to the nearest degree for each milacre plot.

Analysis

The study was designed for multiple regression analysis, with each unreplicated treatment located randomly within the general study area. Milacre plot values for the above-described independent variables were averaged for each treatment to provide a single observation for each variable per treatment.

^{3/} The assistance of Dr. M. A. Radwan, Principal Plant Physiologist, Animal Damage Control Project, Pacific Northwest Forest and Range Experiment Station, in the laboratory phases of calibration, standardization, and measurement is gratefully acknowledged.

Because of the bias introduced by the 10-maximum limit on postlogging seedling counts after 1964, no analyses were performed on final numbers of seedlings data. Analyses were performed for the 1965 data. The only independent variable to survive significance tests ($p \leq 0.05$) was overstory basal area.

LIST OF PLANT SPECIES

Plant species observed on the milacre plots are listed below. Sources for the scientific names are Hitchcock et al. (1955, 1959, 1961, 1964, 1969) for vascular plants except trees, and Little (1953) for trees. Common names are mostly from Peck (1961) and Little (1953).

<u>Scientific name</u>	<u>Common name</u>
<i>Acer circinatum</i> Pursh	vine maple
<i>Alnus rubra</i> Bong.	red alder
<i>Anaphalis margaritacea</i> (L.) B. & H.	pearly everlasting
<i>Athyrium filix-femina</i> (L.) Roth	lady fern
<i>Blechnum spicant</i> (L.) With.	deer fern
<i>Carex</i> spp.	sedge
<i>Dicentra formosa</i> (Andr.) Walp.	western bleeding-heart
<i>Disporum Hookeri</i> var. <i>oreganum</i> (Wats.) Q. Jones	Oregon fairy bell
<i>Epilobium angustifolium</i> L.	fireweed
<i>Galium</i> spp.	bedstraw
<i>Gaultheria shallon</i> Pursh	salal
Gramineae	grass family
<i>Hieracium</i> spp.	hawkweed
<i>Hypochaeris radicata</i> L.	hairy cat's-ear
<i>Lysichiton americanum</i> Hult. & St. John	yellow skunkcabbage
<i>Maianthemum dilatatum</i> (Wood) Nels. & Macbr.	false lily-of-the-valley
<i>Menziesia ferruginea</i> Smith	rustyleaf
<i>Mitella pentandra</i> Hook.	fivepoint mitrewort
<i>Montia sibirica</i> (L.) How.	western springbeauty
<i>Oplopanax horridum</i> (J. E. Smith.) Mig.	devil's club
<i>Oxalis oregana</i> Nutt. ex T. & G.	wood sorrel
<i>Picea sitchensis</i> (Bong.) Carr.	Sitka spruce
<i>Polypodium</i> spp.	licorice fern
<i>Polystichum munitum</i> (Kaulf.) Presl	swordfern
<i>Pseudotsuga menziesii</i> (Mirb.) Franco	Douglas-fir
<i>Pteridium aquilinum</i> (L.) Kuhn. var. <i>pubescens</i> Underw.	bracken fern
<i>Pyrus fusca</i> Raf.	Oregon crabapple
<i>Rhamnus purshiana</i> DC.	cascara
<i>Ribes</i> spp.	gooseberry or currant
<i>Rubus laciniatus</i> Willd.	evergreen blackberry
<i>Rubus parviflorus</i> Nutt.	thimbleberry
<i>Rubus spectabilis</i> Pursh	salmonberry
<i>Rubus ursinus</i> Cham. & Schlecht.	trailing blackberry
<i>Sambucus cerulea</i> Raf.	blue elderberry
<i>Sambucus racemosa</i> L. var. <i>arborescens</i> (T. & G.) Gray	red elderberry
<i>Senecio</i> spp.	ragworts
<i>Stachys mexicana</i> Benth.	great hedge nettle
<i>Tsuga heterophylla</i> (Raf.) Sarg.	western hemlock

No statistical tests were made on regressions depicted in figures 7 and 11 through 18 because of lack of independence between successive measurements made on the same plants. The regressions illustrated, however, are unbiased estimators.



Williamson, Richard L., and Robert H. Ruth
1976. Results of shelterwood cutting in western hemlock. USDA For.
Serv. Res. Pap. PNW-201, 25 p., illus. Pacific Northwest
Forest and Range Experiment Station, Portland, Oregon.

Twelve shelterwood densities, ranging from 38 to 235 square feet of basal area per acre, were created in a 60-year-old stand. Eleven years after the first cut, regeneration was heavily overstocked under all densities. Brush was adequately controlled by overstory densities of at least 90 square feet of basal area. Overstory volume growth per acre during the regeneration period was approximately proportional to number of trees. Based on clearcutting experience on similar western hemlock sites, shelterwood harvesting probably was not essential for successful regeneration at this location. However, shelterwood cutting is a viable alternative to clearcutting for harvesting and regenerating western hemlock.

KEYWORDS: Shelterwood cutting method, western hemlock, silvicultural systems, natural regeneration.

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